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# CEMENT

BY

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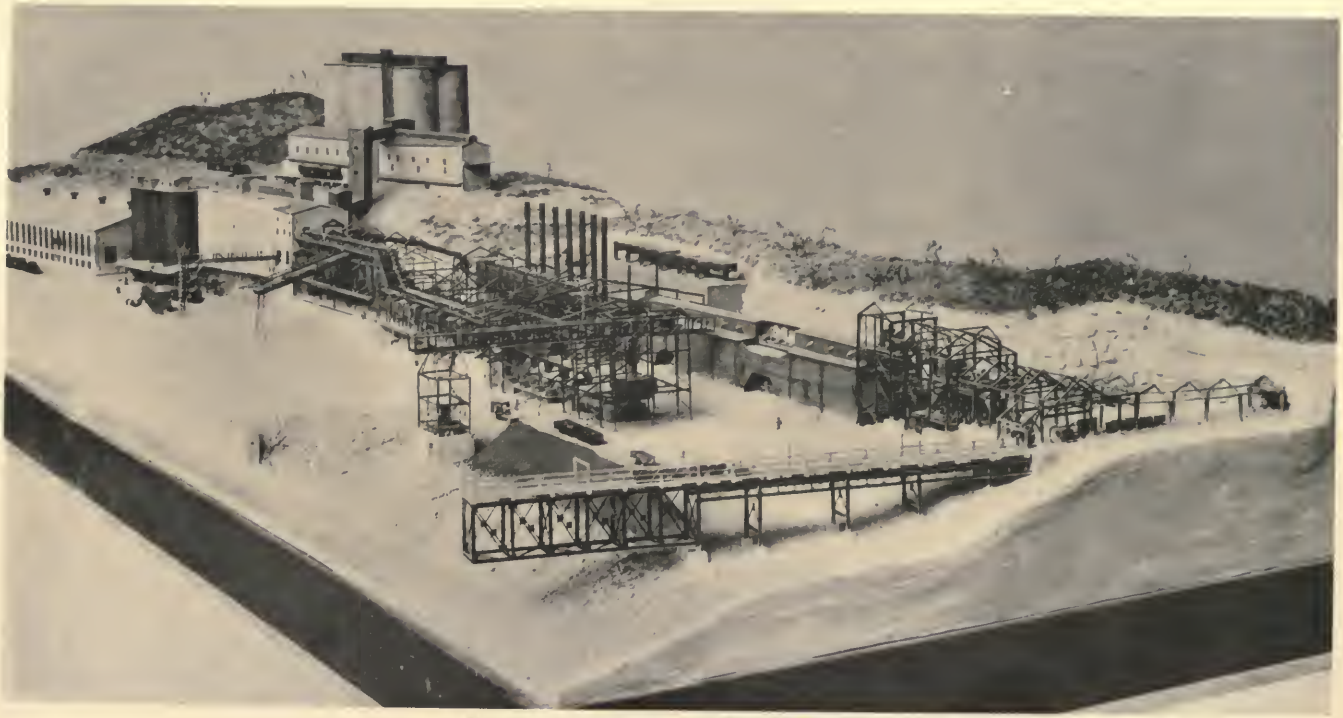

MODEL OF A TYPICAL CEMENT PLANT

The plant of the Marquette Cement Manufacturing Company, near LaSalle, Illinois

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# CEMENT

In 1824, little more than a hundred years ago, an English mason, Joseph Aspdin, made a discovery which has revolutionized the building and engineering industries and which now forms the basis of one of the major industries of all civilized countries. He burned an intimate mixture of powdered limestone and clay until clinkers formed and then ground these clinkers to powder. He then had a powder which when moistened solidified to a mass resembling limestone. This he called "portland cement," because the hardened material resembled the Portland stone which was a common building material of the period. What he had was practically a plastic rock which could be molded into any form or could be used to combine any number of separate stones into one essentially monolithic mass. Moreover, the material was, even at that time, not expensive, for the raw materials, limestone and clay, were readily obtained and were as cheap as any raw materials could be. The process of manufacture was simple, merely grinding and burning, and the product compared favorably in its properties with ordinary building stones. The economy of its use was enhanced by the fact that it could be, and universally is, used diluted with six or more times its weight of common sand, gravel and broken stone.

Structural cements had been used long before the time of Joseph Aspdin and several cements other than port-

land are even now extensively used for special purposes, but the use of portland cement is so overshadowing that when the word cement is now used portland cement is commonly understood. Where strength is not important, the usual mixture of lime and sand, known as mortar, is generally used. This is often strengthened by the addition of portland cement. The asphaltic and bituminous cements used by the Babylonians still compete with portland cement as street-paving material. The burnt gypsum cements, of which plaster of Paris is perhaps the most familiar, are of ancient origin and play an important part in modern industry. In regions where there is little rainfall, mud is used as mortar for stone or adobe walls and even wattle and mud houses are not uncommon. The Romans made a cement having many of the qualities of portland cement, from a mixture of lime and volcanic ash. Concrete made from this cement is very durable and buildings constructed of it in Roman times persist to the present day.

Another cement, called natural cement, is made from limestone which has been formed in muddy water and is contaminated with clay. When the clay content of such limestone approaches that of the limestone and clay mixture for portland cement, the rock is called hydraulic limestone or waterlime because lime burned from it will set under water. If such a rock is burned at the proper temperature and the resulting clinker ground, a cement very like portland cement is formed. This would be identical with portland cement if the proportions of limestone and clay were exactly right and no injurious impurities were present. Unfortunately this is seldom the case, so the natural cement rarely equals the quality of portland. Also, the possible output of natural cement is limited, as suitable beds of the raw materials are not common. Natural cement was in use at the time of the discovery of portland cement and its use has persisted,

although in a minor way, quite to the present day. From other combinations of mineral substances, other cements suited to special purposes are made, but the combined use of all these does not compare with the consumption of portland cement.

While most portland cement is burned from limestone and clay, it has been found that slag from iron blast furnaces can be substituted for clay. Large quantities of cement from this mixture are made near Chicago. The limestone used in many plants is contaminated with much clay, which is compensated for by the addition of less clay to the mixture. In other plants the lime is used in the form of marl, chalk or even shells. Not all limestones and clays are fit for cement manufacture, as mineral substances are often present which seriously affect the quality of the cement. In all modern plants everything going into the cement is analysed and the output is regularly tested for quality. Continuous chemical control is one of the most important features of the process.

As the manufacture of portland cement involves only a few grindings, a mixture and a burning, it might be supposed that cement plants would be very simple. In the past this was true and it is quite possible even now to make cement with no other equipment than a pestle and mortar and a kitchen stove. The enormous production of cement for use in the building and engineering industries, (in 1926 over 30,414,828 tons were used in the United States alone) is, however, possible only because the cement can be provided at low cost and of uniform quality. If cement were still made in small plants with simple appliances, its use would be greatly restricted.

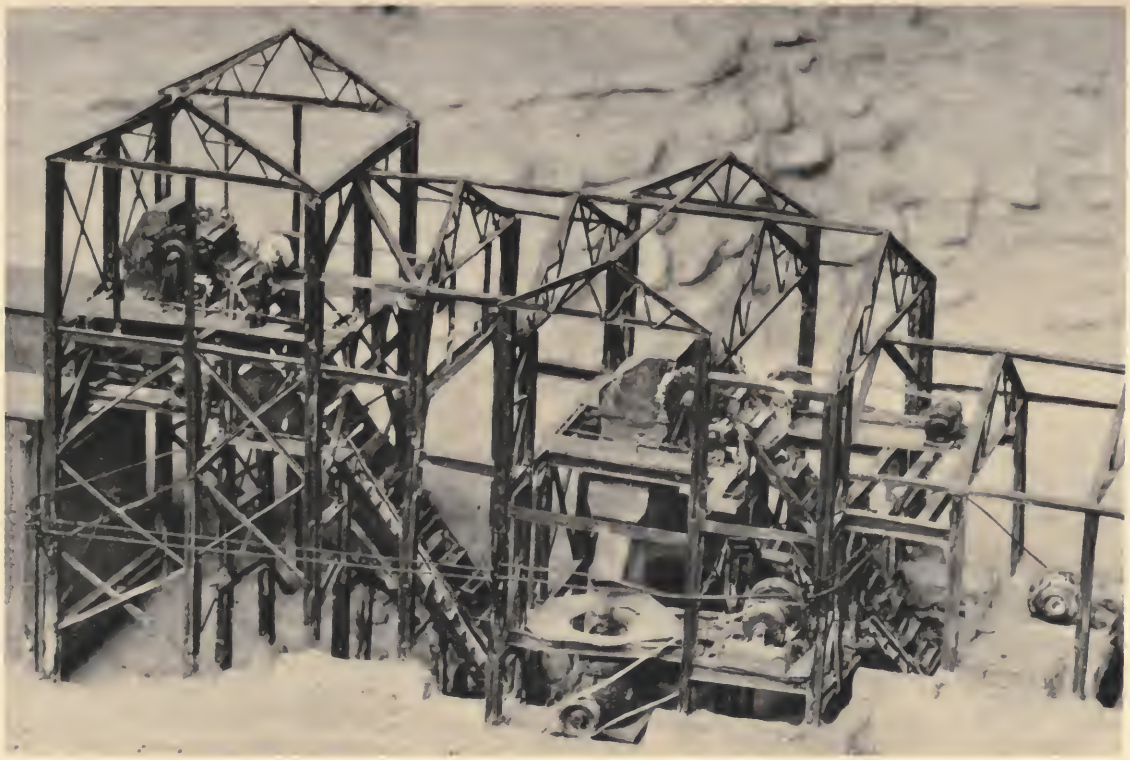
The modern cement plant is large and is equipped with the most elaborate machinery for the purpose of eliminating labor and reducing costs in every possible way. The large size and elaborate equipment of a plant

such as is required for the successful manufacture of cement under modern industrial conditions, is well illustrated by the model of a typical cement plant which is exhibited in Hall 36 of the Museum. This model (Frontispiece) represents the plant of the Marquette Cement Manufacturing Company located on the banks of the Vermillion River near La Salle, Illinois. Though not the largest, this plant produces 32,000 sacks of cement daily.

The model is made of portland cement and is on a scale of twelve feet to the inch. It occupies a space of twelve by three feet and represents an area of 1,728 by 432 feet. It is a realistic model, that is, all features are given as life-like an appearance as possible. It is accurately laid out from architects' and engineers' plans and departs from an accurate miniature of the works only in the omission of walls and roofs where necessary to show machinery inside buildings and in the omission of accessory buildings, such as administration quarters, laboratories and workshops. It shows all stages of the process from the mining of the clay and limestone to the loading of the sacks of cement on the cars.

For the purpose of description the plant may be separated into seventeen units, each separately housed. These are: 1, the mine; 2, the crushing plant; 3, the rock storage; 4, the raw mill; 5, the kilns; 6, the coal pulverizing mill; 7, coal storage and handling equipment; 8, the waste heat plant; 9, the clinker cooling and storage; 10, the bag house; 11, the finishing mill; 12, the cement storage; 13, the bagging machines; 14, the power house; 15, shipping platforms and the railroads; 16, water purifying plant; 17, chemical laboratories, administration building, repair shops and miscellaneous equipment.

An elaborate system of traveling belts, conveyors and elevators takes the output of each machine to the next and the output of each building to the next without the intervention of human labor. The result is that the mill



DETAIL FROM MODEL OF CEMENT PLANT

The crusher house, showing rock crushers and conveying machinery

is operated by surprisingly few laborers for its size. It produces about 60 sacks of cement per day for each laborer employed.

The detailed description which follows illustrates well the extent to which in modern industry machinery replaces human labor and also the extent to which modern industry eliminates waste and saves costs by the installation of elaborate machinery.

The mines furnish the raw materials, limestone and clay; the latter is in the form of shale or hardened clay. Most cement plants obtain their limestone from quarries and their clay from pits. The Marquette company is peculiar in that it mines its limestone and clay from beneath the surrounding hills. Parts of this mine may be seen at the rear of the model. In this mine a bed of limestone overlies a bed of shale. The limestone is mined according to the room and pillar system of the coal mine. After the limestone has been mined, the clay is taken. First the limestone is drilled and blasted, then the broken rock is loaded into cars by a shovel like a steam shovel, which is operated by compressed air.

The cars are made up into trains which are drawn by electric locomotives to the first building of the mill, the crusherhouse, Plate 1. Here, after being weighed, each car is gripped by a powerful machine that turns it bodily upside down and empties the contents into a chute which leads to the automatic feeder of the first crusher. This feeder delivers the rock to a gigantic jaw crusher which can take four by five foot pieces of rock and reduce them to six inch lumps. It can when necessary crush 400 tons of limestone per hour. The crushed stone falls from the crusher to an elevator which raises it to the top of the building and delivers it to two smaller crushers which finish the comminuting by reducing the lumps to two and one-half inch pieces. The crushed material falls on a system of conveyors, elevators and belts which carry it

to the next building, where it is stored until needed. The crushing plant works for a time on limestone alone and then on clay alone. The two materials are not mixed until they are about to leave the point of storage.

The rock materials are stored in a long building which houses a row of bins, some for limestone, some for clay or shale. The conveyor belt from the crusher house runs over the top of these bins. An unloading machine or tripper is set by the attendant to unload the belt into any bin at his will. These storage bins discharge at the bottom onto another conveying belt which takes the material to the next stage of the process as it is needed. The discharge of each bin is through an ingenious measuring gate which can be set to deliver any desired quantity of limestone or clay. It is on this belt that the limestone and clay mixture is made, by setting the measuring gates to deliver the quantities of each which have been calculated after analysis of the contents of the bins by the plant chemists.

The storage of materials serves several purposes. The mine may shut down temporarily without stopping the mill or the mill without affecting the mine. Minor variations in composition of the clay and limestone are smoothed out by drawing material simultaneously from many bins which have been loaded at different times. Also time is provided for the chemical analyses of the materials needed to control the quality of the cement and means are provided by which the mixture of clay and stone may always be kept uniform.

The crushed clay and stone, mixed in the desired proportions, then goes to the raw mill. In the raw mill the crushed clay and limestone are ground to a flour-like powder and intimately mixed for burning.

Two methods of grinding, wet and dry, are in use in cement mills. In wet mills the mixture is ground in water to a mud called "slurry." In dry mills the dry mixture

is ground to an impalpable powder, so fine that seventy-eight per cent must pass a screen having 40,000 openings per square inch. This is finer than silk is woven. The Marquette Plant is a dry mill. Slightly damp material cannot be economically ground to powder, as it would cake in the mills. Consequently the first step in the raw mill is to dry the raw material. The belt from rock storage delivers its load to elevators which raise it to bins near the roof. These bins discharge into coal-fired drying kilns, where the materials are completely dried. The output of these driers falls to conveyors in conduits under the floor, from which it passes to elevators which distribute it to the elevated feed-bins of a battery of grinding mills. In these mills the lumps of clay and limestone are crushed and ground to powder by the action of steel rolls passing over an annular steel anvil. During the grinding the particles of clay and stone become very intimately mixed.

The fine powder emerging from the mills is taken by another set of conveyors and elevators to elevated bins in the kiln house. In the kiln house, Plate II, a vital part of the process, burning the powdered rock to clinker, takes place. The kilns (there are seven of them) are long, horizontal cylinders of steel, lined with fire-brick. Electric motors acting through gears keep these cylinders turning. They are very large. Each is nine feet in diameter and one hundred feet long. They are fired by powdered coal which is blown into the forward end by a blast of air, while the products of combustion escape from the rear into flues. The coal comes to the mill by rail and is unloaded and piled by cranes.

An overhead crane takes coal from the stock pile to the coal-grinding mill which is much like the raw mill already described. In the coal-grinding mill the coal is first dried by passing through dryers and then fed to grinding mills which reduce it to powder. This powder

is taken to the kiln house by conveyors and blown in the form of dust into the kilns by a blast of compressed air. In the kilns it burns with a long, intensely hot flame which looks like a gas flame. The limestone and clay powder is taken from bins above the revolving kilns by conveyors which drop it into the kilns at the rear. The revolutions of the constantly turning kiln tumble the powder forward until it discharges at the front into a brick-lined chute. During this passage it becomes exceedingly hot. It is estimated that the temperature of the hottest part of the cement kiln is 3,000° F., one of the highest temperatures used in industry. The clay and limestone are very infusible and do not melt even at this high temperature. They do, however, soften and become decidedly pasty. Now, the reason for the necessity of grinding the stone and clay so very fine and of mixing the powders so thoroughly becomes apparent. Wherever a particle of clay touches a particle of limestone at this elevated temperature, there occurs a migration of atoms from one to the other, so that wherever these minerals are in contact they lose their identity and a number of new minerals are formed. These minerals, formed at high temperatures, are not stable in the presence of water. If they are powdered and then moistened, the water decomposes them and new hydrous compounds are formed which have great cohesive and adhesive properties. The heat-softened material, passing through the kiln, agglomerates, while in a pasty state, to nodules, which are discharged from the kiln in a form resembling the clinkers made by an ordinary coal fire. This product, called clinker, is so hard that it will scratch glass. It falls through brick chutes to conveyors which conduct it to the next stage of the process.

The products of combustion, on leaving the rear of the kilns, are very hot and the utilization of this heat is well worth while. Hence, these hot gases are passed

through waste-heat boilers and provide steam enough to operate the entire plant, including the generating of electric current for the mine. Besides the gaseous products of combustion, much dust is present in the flue gases. These, therefore, before going to the boilers are passed through a settling flue. Much of the dust, too light to be retained by this settling chamber, passes through the boiler and would escape through the stacks were they not provided with dust catchers. These hold the dust and this, together with that from the flues, is returned to the process. Thus a not inconsiderable loss is averted.

The waste-heat boilers are very large. They are like the large types of coal-fired boilers with some modifications. The steam they make goes through large pipes to the power plant, several hundred feet away.

Clinker from the kilns, as it enters the conveyor, which takes it to the next stage of the process, is very hot, so that the first thing to do is to cool it. This conveyor consists of a series of shallow, heavy, metal pans hinged together. It is very long and conveys the clinker by a lengthy, round-about course over the tops of the buildings to the cooling towers. By virtue of its long passage through the open air, by the time it reaches the towers it has lost much of its heat. The cooling towers are large, vertical, iron cylinders open at the top over which the conveyor passes. Automatic trips are arranged so that the conveyor pans may be made to discharge into any tower at will. Large volumes of air are blown into these towers from below and the air blast rapidly cools the clinker, which is then drawn off from below to feed the finishing mill.

When all the kilns are in operation, more clinker is produced than the finishing mill can handle. The excess, instead of going to the cooling towers, is stored in a stock pile out in the open air. This is accomplished by tripping

the conveyor pans over the top of an inclined chute which deposits the clinker in a pile away from the buildings. Here it remains exposed to the weather until it is wanted. It is a curious fact that wetting the clinker by rain does not injure it, but if the same material is ground to a powder, the addition of water will cause it to set and form a hard mass. When clinker from the pile is wanted, a clam-shell dredge mounted on a flat car feeds it to a conveyor-elevator by which it returns to the finishing mill.

In the finishing mill the clinker is ground to a powder which, as already noted, is so fine that at least 78 per cent of it will pass through a bronze sieve of 40,000 meshes to the square inch. This grinding is performed in two stages. There is first a coarse grinding in large mills in which metal rolls revolve at high speed on circular tracks. This is followed by a final treatment in ball mills. These are horizontal, revolving cylinders, partly filled with manganoid steel balls which tumble over each other as the mill revolves. The particles of clinker passing among these tumbling balls are ground to fine powder and the cement is finished.

A plain cement sets somewhat faster than is desirable and on account of unavoidable minor variations in the composition of the mixture and in the heat of the kilns, different lots of cement will have somewhat different times of setting. There are several substances which added to cement will delay the time of setting. Cement manufacturers have found that the most satisfactory substance for this purpose is gypsum. A very small addition of raw gypsum has a marked effect upon the time of setting. Before the clinker goes to its final grinding, samples are ground in the laboratory and the time of set determined. Then the amount of gypsum needed to change this time to the standard time of set for the brand of cement being made is calculated. This amount

is fed by automatic machinery to the clinker in the finishing mill.

Conveyors take the finished cement to the cement storage which is in groups of tall, round tanks resembling farmers' silos or late designs in grain elevators. Most cement is sold in cloth sacks holding ninety-four pounds each. Paper sacks are also used. The filling of so many sacks would be a serious task were it not for the bagging machines which automatically put exactly ninety-four pounds of cement into each bag. All the labor needed is that of one man to a machine to place the empty sack over a spout. The sack then fills and when the correct weight of cement has entered, it drops off the spout already tied and falls to the shipping platform, where men with trucks load it into a waiting box car. The peculiar thing about this operation is that the bag is tied first and filled afterwards. This somewhat paradoxical operation is made possible by the valve in the bag. On examining a used cement bag one will find at one end of the seam across the bottom an opening which looks like an accidental rip. At the side of this rip at the corner of the bag is a little ear of cloth such as is often accidentally present at such corners. This is the valve. The bag is filled through this opening and the weight of the cement causes the ear of cloth to lie against the opening and close it.

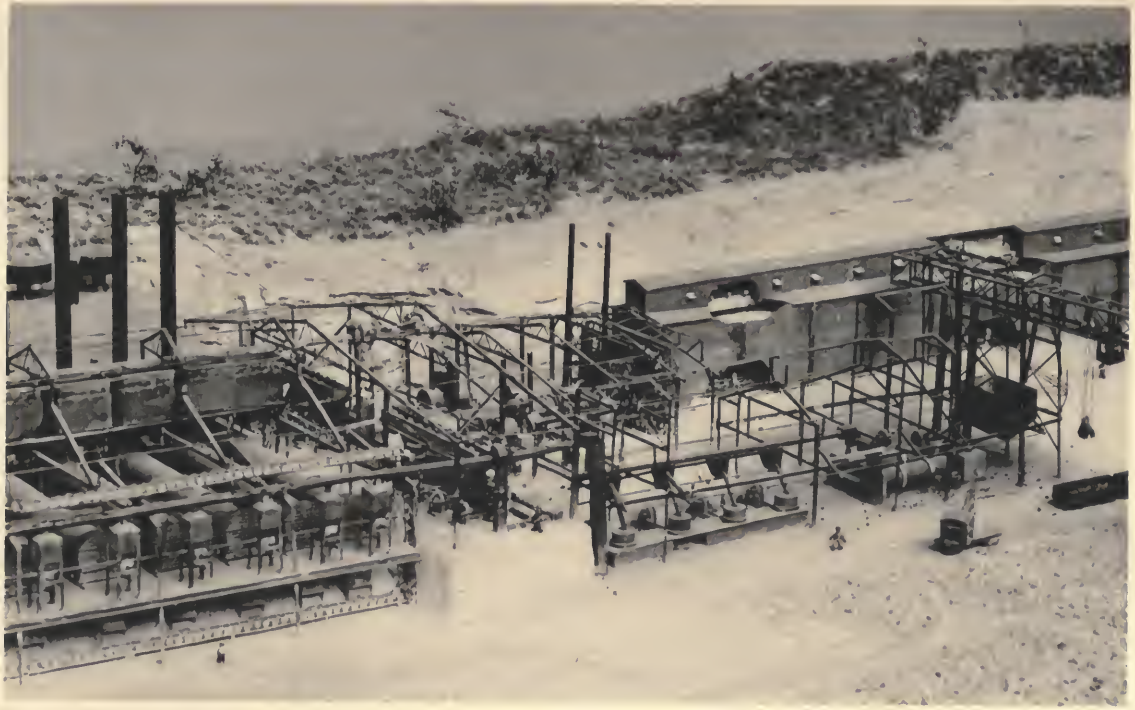
Beyond the finishing mill is a power house. Here steam engines and turbines supplied with steam from the waste heat boilers drive electric generators which provide power for operating both the mill and the mine. These engines also drive air compressors, which feed the drills in the mine and provide the air blast needed in several stages of the process.

In addition to these essential parts of the mill, there are a number of buildings which house necessary auxiliary services and which are not included in the model.

These include a water purifying plant, chemical laboratories, administration building, repair shops, material storage and other minor features.

Cement is seldom used alone. Important quantities are used mixed with sand, as plaster, stucco and mortar. Also large quantities are used as bonding material for special products, such as asbestos lumber and shingles. The greater part of all cement made is used as concrete. Concrete is a mixture of cement with sand and pebbles or crushed stone. The material mixed with the cement is called the aggregate. Aggregate is of two kinds, fine aggregate, usually sand or screenings from crushed stone, and coarse aggregate, usually pebbles or crushed stone, although other substances, cinders for example, may be used for special purposes. While cement is the essential ingredient of concrete, it is in quantity but a minor part of the mixture, for if more is used than suffices to bond securely the particles of rock and sand, the quality of the concrete suffers. The exact quantity of cement used will be different with differences in the aggregate, but will not be very different from the typical mixture of one part cement to two parts sand and four parts pebbles or stone (measured by volume). Much concrete is used for purposes in which the whole of its great strength is not needed and for such purposes a "leaner" concrete with even less cement is satisfactory and is extensively used.

Concrete shares with stone one serious defect which, if means had not been discovered to counteract it, would greatly lessen its use. Stone and concrete effectively resist crushing, but neither is comparable to wood or iron when pulling or bending strains are to be sustained. There are, therefore, many structural uses for which stone and plain concrete are absolutely unsuited. For this defect the remedy is the use of reinforced concrete. In this material the tensile stresses which the concrete cannot successfully resist are taken care of by steel rods



DETAIL FROM MODEL OF CEMENT PLANT

Showing battery of kilns

or wires imbedded in the mass. Of concrete reinforced in this way practically any kind of structure can be made.

There are certain uses for which ordinary portland cement has not proven wholly satisfactory and for these special cements of the same general nature as portland have been developed.

By care in selecting pure material accompanied by minor changes in methods of manufacture a white portland cement is made which is used where the dark color of ordinary cement is objectionable.

To obviate delay in construction due to the slowness with which ordinary cement hardens and acquires strength two modified cements are made. These are used in no insignificant quantities in work where delay is serious.

One of these, accelerated portland cement, which has a strength when three days old equal to that of ordinary cement at 28 days differs but little in composition from the regular portland. The composition is slightly modified but the principal benefits are secured by care in eliminating deleterious matter from the raw material, by extreme care in manufacture and by finer grinding.

The other early strength cement, used principally in Europe, is called Alumina cement because alumina is substituted for the silica of portland cement. This is made by melting together limestone and the aluminum ore, bauxite and grinding the resultant slag.

Portland cement is corroded by sea water and by heavily mineralized ground waters. Hence there are objections to its use exposed to sea water or for foundations in certain regions. Alumina cement resists this corossion and is coming into use in such situations.

Portland cements are now being modified to resist this destructive action by grinding them with mineral additions such as silica or volcanic ash.

A glance around in any large city will give some impression of the extent to which cement enters into modern life. Concrete sidewalks, streets, lamp-posts, buildings, Plate III, and a host of other objects of cement are everywhere present. But the visible concrete is but a small part of that actually employed. Thousands of tons are buried as foundations under buildings. Many walls, apparently of brick or stone, are really concrete walls faced with brick or stone for appearance. In many large office buildings the floors are of concrete covered with wood or other suitable surface. Even in steel buildings, concrete in large quantity enters into the construction for foundations and fireproofing and an increasingly large number of buildings are built entirely of concrete except for facings of other materials applied for appearance. Although most concrete buildings with any pretension to beauty are veneered with other material this is not always the case for concrete surfaces of pleasing aspect can be prepared. Naturally the expense is greater than that of rough surfaces. A fine example of such treatment is Chicago's Municipal Amphitheatre, Soldier Field, Plate III, with its attractive finish resembling granite. Smaller buildings are frequently constructed of cement block which have surfaces resembling a great variety of building stones. In some parts of the world highly ornate floor tiles formed under hydraulic pressure from colored cements are in extensive use and cannot be readily distinguished from terra cotta. While concrete finds an extensive use in the development and progress of urban life, its application in other fields is also worthy of mention.

Were it not for concrete (man-made stone) such structures as the Panama Canal, the Catskill Aqueduct, the Roosevelt Dam and the great amphitheaters for athletic contests would hardly have been possible. If they were built of other material, using an equally sub-

stantial form of construction, the cost involved would have been prohibitive. This would likewise be true of the vast network of permanent concrete highways that now band our nation from coast to coast. Then, too, if it were not for concrete, farms would not enjoy the convenience, sanitation and economy of operation that now is theirs. Concrete is a material in which we truly place much dependence and its value to us has been brought about by the production of portland cement in such plants as the one described and illustrated herein.

HENRY W. NICHOLS

A CONCRETE BUILDING

Soldier Field as seen from Field Museum of Natural History

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